DAVIS STRAIT: MARINE GEOLOGY, SEDIMENTOLOGY, AND ICEBERG SCOURING ANALYSIS

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ABSTRACT

The results of data analyses suggest that the surficial sediment at the Hekja-Ralegh survey area was initially deposited in a proglacial marine environment, possibly beneath an ice shelf; iceberg scouring has since dislodged and redistributed the bottom sediment. Strong bottom currents have removed most of the surficial (top 5-10 cm) silt and clay which accounts for the paucity of such material. Iceberg rafting is probably responsible for the anomalous coarse gravel fraction found in many samples.

Examination of the sediment cores indicate that scouring of the seabed is not a modern phenomenon at these water depths (225 to 400 m). Cores show both sedimentological and micropalaeontological hiatuses, believed to indicate scouring, overlain by at least one half metre of undisturbed sediment interpreted as post-scour infill. Amino acid racemization of a core collected in 1981 at the Hekja site suggests a probable maximum age of 20,000 years BP. Correlation of the newly collected cores with the Hekja 1981 core suggests that the scouring events recognized in three of the cores range between 5,000 and 15,000 years in age. The scours found at this depth are almost certainly relict and most probably predate the Hall Ice advance of 10,760 years BP.

TABLE OF CONTENTS

	Page
ACKNOWLEDGEMENTS	i
ABSTRACT	iii
TABLE OF CONTENTS	v
LIST OF FIGURES	vii
LIST OF TABLES	ix
INTRODUCTION	1
Objectives	4
SEDIMENTOLOGY	7
Previous Work	7
Sediment Textural Analysis	9
Sediment Grain Size Analysis	13
CORE LOGGING	23
STRATIGRAPHIC CORE ANALYSIS	25
Sediments	25
Normal Succession	26
Broken Succession	27
Microfossils	27
GEOTECHNICAL ANALYSIS	37
Natural Moisture Content	37
Bulk Density	37
Atterberg Limits	38
Summary	38
SUMMARY DISCUSSION AND MODEL	39
CONCLUSIONS	43
REFERENCES	45

LIST OF FIGURES

		Page
Figure 1	Survey site indicating sample grid pattern and the sites where 107 sediment grabs and cores were collected	x
Figure 2	Huntec DTS profile showing the acoustically homogeneous overburden draping the older relatively smooth bedrock surface	6
Figure 3	(a) Textural composition of surface sediment grab samples using the entire sample (b) Textural composition of surface sediment grab samples excluding the gravel component	12
Figure 4	Generalized grain size cumulative frequency curve shapes for Hekja-Ralegh samples	14
Figure 5	Map illustrating the random distribution of the three groups of grain size cumulative curves	15
Figure 6	Bivariate plots of statistical parameters for surface grab samples from the Hekja-Ralegh area. Parameters have been derived from cumulative frequency curves (a) Mean size versus standard deviation (b) Skewness versus standard deviation	18
Figure 7	Bivariate plots of statistical parameters for surface grab samples from the Hekja-Ralegh area. Parameters have been derived from cumulative frequency curves (a) Kurtosis versus mean size (b) Kurtosis versus skewness	19
Figure 8	Comparison of Hekja-Ralegh sediments with data for till, alluvial fan and glacial outwash material (compiled from Landim and Frakes, 1968) (a) Mean versus standard deviation (b) Kurtosis versus mean size	20
Figure 9	Comparison of Hekja-Ralegh sediments with data for till, alluvial fan and glacial outwash material (compiled from Landim and Frakes, 1968)	

(a) Skewness versus standard deviation

(b) Kurtosis versus skewness 21

Figure 10 Graphical representation of foraminiferal frequency along the length of the control core (Core No. 22) collected north of the Ralegh Wellsite 28

Figure 11 Graphical representation of foraminiferal frequency, Core No. 07, collected immediately east of the Ralegh Wellsite. Scouring event inferred at the 65 to 70 cm level 30

Figure 12 Graphical respresentation of foraminiferal frequency, Core No. 20, collected west of the Ralegh Wellsite 32

Figure 13 Graphical representation of foraminiferal frequency, Core No. 27, collected north of the Hekja Wellsite 33

Figure 14 Generalized model of physical processes influencing and contributing to sedimentology of the southeast Baffin Island continental shelf 41

LIST OF TABLES

		Page
Table 1	Core samples station data	2
Table 2	Bottom grab samples station data	3
Table 3	Textural compositions of sediment grab samples from the Hekja-Ralegh survey site	11
Table 4	Location of cores used in geotechnical analysis ..	36

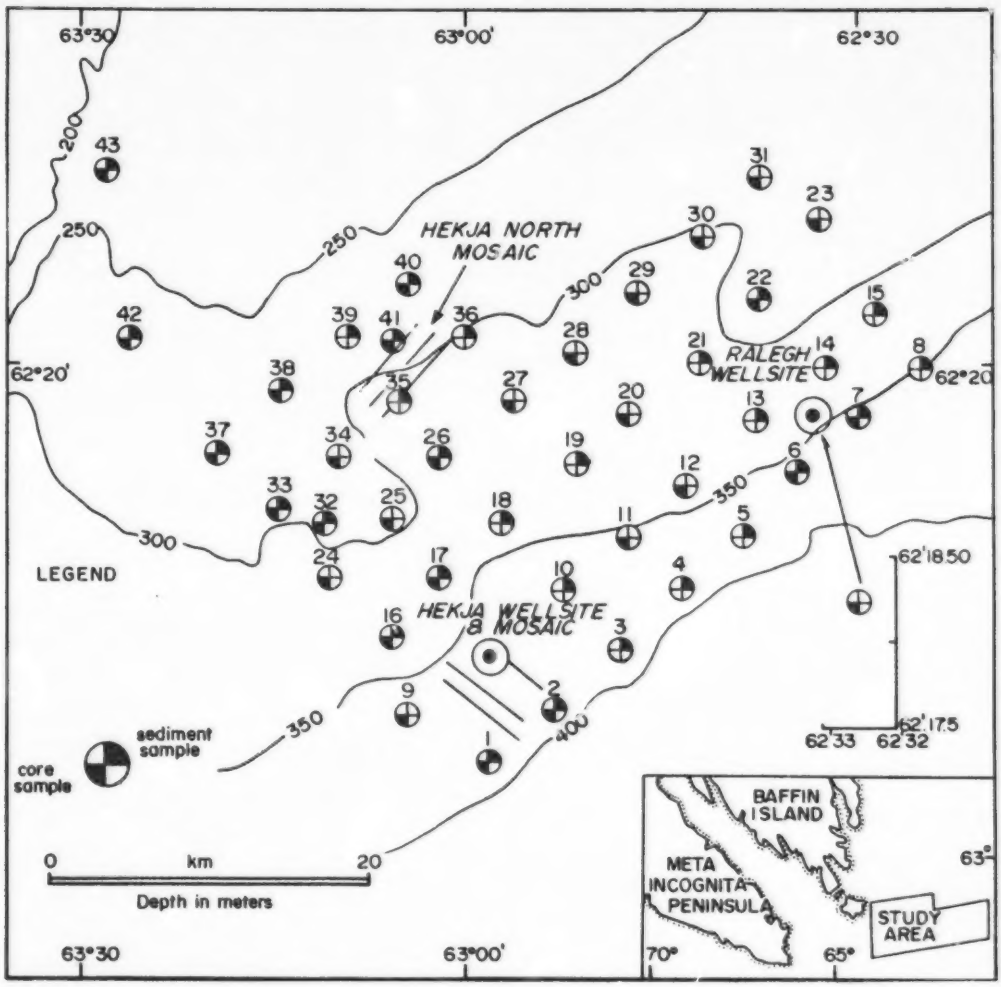


Figure 1. Survey site indicating sample grid pattern and the sites where 107 sediment grabs and cores were collected.

INTRODUCTION

This study, undertaken during 1982 and 1983, is a result of recommendations for further research made at the end of an initial study, undertaken in 1981 on iceberg scouring in the Davis Strait area (Pereira 'et al.', 1983). Knowledge of the shelf physiography and processes were required to assess possible methods and routes of transporting hydrocarbons in the event that hydrocarbons are found in economically recoverable quantities.

During the months of June/July 1982, Geomarine (Newfoundland) Ltd., St. John's, under contract to Canterra Energy Ltd., operator for the Baffin-Labrador Group of Companies comprising Canterra Energy Ltd., Petro-Canada Exploration Inc., PanCanadian Petroleum Ltd., Murphy Oil Company Ltd., Home Oil Ltd. and SOQUIP, undertook a surface sediment and coring program in the Hekja and Ralegh wellsite vicinities, on the southeastern Baffin Island continental shelf (Figure 1). Also included in the sampling program were samples from within the 1981 Hekja North mosaic area, the Ralegh wellsite and from a seabed feature interpreted to be a submarine mud volcano (Woodworth-Lynas, 1983). The samples were collected at water depths of between 225 and 400 m, in an area where extensive iceberg scouring had occurred. Sample stations other than those for the Hekja North mosaic area, and the immediate Ralegh wellsite follow an orthogonal grid pattern at roughly 5.0 km spacing covering the area surrounding the two wellsites (Figure 1). In all, a total of 107 samples were collected from 44 stations. Of the 107

samples collected, 52 were cores. Sediment samples were collected using a Van-Veen grab and weighed between 0.25 and 1.0 kg each. The gravity cores retrieved vary in length between 10.5 and 120 cm.

Tables 1 and 2 list the sediment grab and core samples that were examined in this study.

TABLE 1

CORE SAMPLE STATION DATA

SAMPLE NO.	LOCATION		WATER DEPTHS	REC. PENETRATION
	Lat.	Long.	metres	cm
07	62° 17.22'	62° 27.26'	362.10	80.00
09	62° 08.04'	63° 00.24'	371.25	25.00
12	62° 15.41'	62° 41.00'	341.99	19.00
20	62° 17.52'	62° 45.23'	329.18	68.00
22	62° 21.42'	62° 35.17'	279.81	115.00
25	62° 14.68'	63° 04.03'	299.00	50.00
27	62° 18.37'	62° 54.00'	329.00	80.00
31	62° 25.33'	62° 34.30'	288.95	14.00
37	62° 17.06'	63° 16.57'	not recorded	30.00
38	62° 19.07'	63° 12.21'	281.64	20.00
40	62° 22.50'	63° 02.43'	281.64	38.00
41	62° 20.73'	63° 03.36'	296.27	52.00
42	62° 20.46'	63° 24.26'	268.83	36.00
43	62° 26.34'	63° 25.00'	221.30	14.00
43	62° 26.34'	63° 24.40'	228.60	13.00
44	62° 18.04'	62° 32.50'	332.23	67.00?
44	62° 17.59'	63° 32.40'	335.89	60.00?

TABLE 2

BOTTOM GRAB SAMPLE STATION DATA

Sample No.	LOCATION Lat.	LOCATION Long.	WATER DEPTH metres
01	62° 06.33'	62° 56.78'	not recorded
02	62° 08.18'	62° 51.69'	not recorded
03	62° 10.07'	62° 46.59'	391.97
04	62° 12.03'	62° 42.09'	395.02
05	62° 13.84'	62° 37.04'	380.39
06	62° 15.48'	62° 32.36'	376.73
07	62° 17.55'	62° 27.41'	356.62
08	62° 19.16'	62° 22.66'	358.44
10	62° 12.24'	62° 50.83'	390.00 approx.
13	62° 17.60'	62° 35.73'	341.99
15	62° 21.12'	62° 26.51'	318.21
16	62° 10.87'	63° 04.35'	340.16
17	62° 12.46'	62° 59.44'	not recorded
18	62° 14.47'	62° 54.90'	347.47
19	62° 16.21'	62° 50.03'	331.01
21	62° 19.81'	62° 40.17'	316.38
22	62° 21.69'	62° 35.20'	279.81
26	62° 16.49'	62° 59.08'	329.18
32	62° 14.47'	63° 09.37'	294.44
33	62° 15.05'	63° 12.80'	296.27
35	62° 18.47'	63° 03.11'	318.21
36	62° 20.43'	62° 58.20'	305.41
37	62° 17.18'	63° 16.88'	285.29
38	62° 19.03'	63° 12.07'	291.39
39	62° 20.86'	63° 07.17'	283.46
40	62° 22.46'	63° 02.39'	283.46
41	62° 20.68'	63° 03.55'	not recorded
42	62° 20.45'	63° 24.39'	259.69
43	62° 22.51'	63° 25.08'	215.80

Objectives

The objectives of the study submitted to Canterra Energy Ltd. in April, 1982 for approval were as follows:

(i) to develop a physical sedimentological model for the continental shelf margin, southeast of Baffin Island;

(ii) to analyse the microfossil and sediment content of cores collected to determine the stratigraphic record for the area and to identify any scouring events within the cores, indicated by sharp, marked changes in microfossil and/or sediment succession;

(iii) to establish definite ages for scouring events using microfaunal, radio isotopic and amino acid racemization techniques;

(iv) to examine the geophysical records collected with reference to potential geological hazards for a prospective pipeline route;

(v) to determine the geotechnical characteristics of the sub-surface sediments through the analysis of ten cores; and

(vi) to collect additional data to substantiate or refute an observation made from previous data, of a submarine mud volcano as a potential geohazard.

This report describes the marine environment of the surveyed southeast Baffin Island continental shelf. Sea floor morphology and sediments are discussed in relation to the physical environment. A generalized sedimentological model for the continental shelf is proposed on the basis of the textural

characteristics of the surficial sediments. Cross correlations between the examined 1982 cores are made using amino acid racemization results obtained for a core (HU81-045-44, see Pereira 'et al'., 1983) collected in 1981 from the Hekja wellsite area (Figure 1).

The geophysical records pertaining to a possible pipeline route were examined and reported on by GEONAUTICS Ltd. of St. John's (Geonautics, 1982). The geotechnical analysis of the core samples was undertaken by Dr. T.R. Chari, of Memorial University of Newfoundland, an abstracted version of which is reported here. The complete report is available at the Ocean Engineering Information Centre, OEIC, at C-CORE. C. Woodworth-Lynas examined the bathymetric and geophysical records collected by Geomarine (Newfoundland) Ltd. pertaining to the mud volcano; the results are presented in a C-CORE technical report (Woodworth-Lynas, 1983).

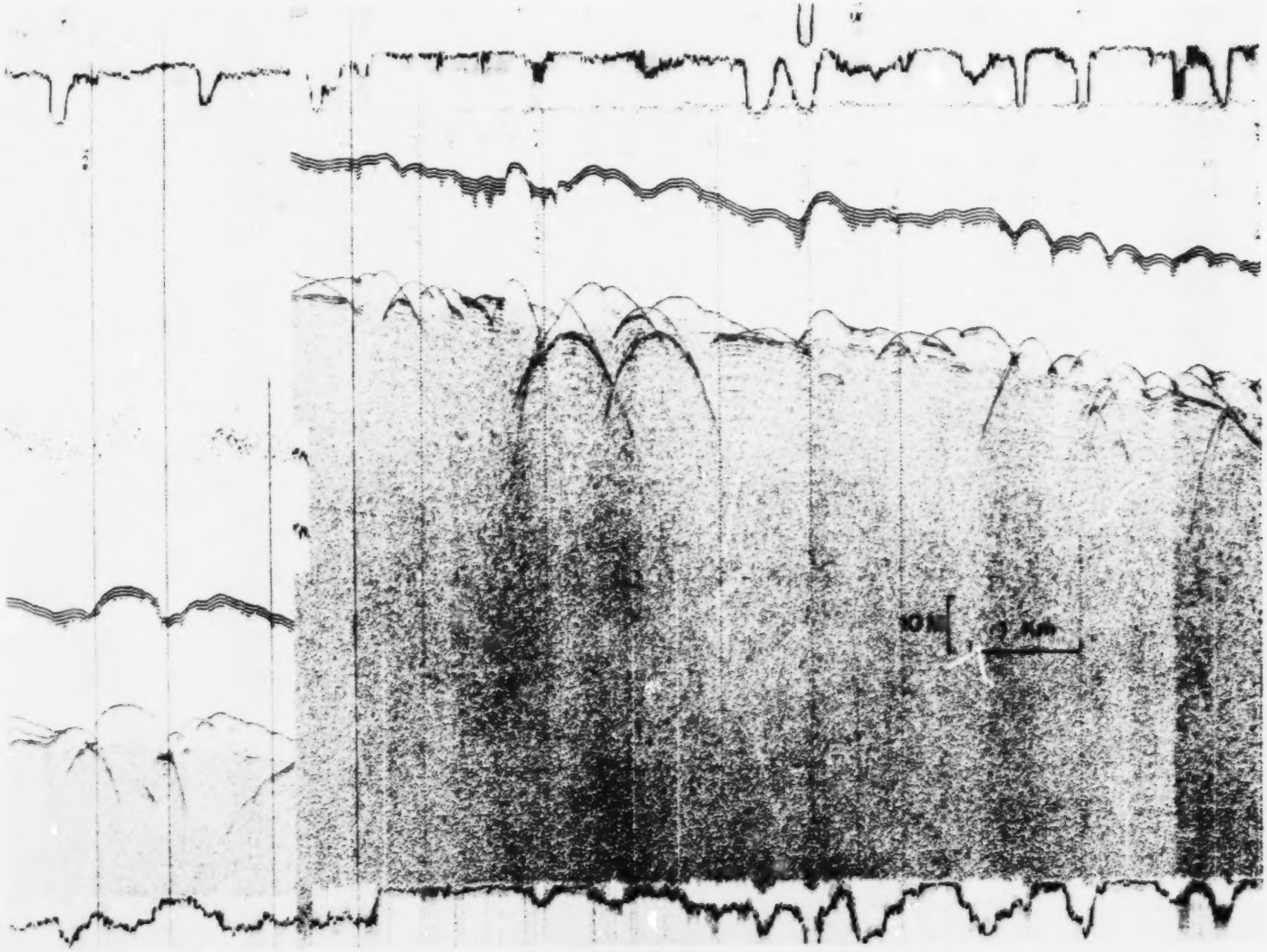


Figure 2. Huntec DTS profile showing the acoustically homogeneous overburden draping the older relatively smooth bedrock surface.

SEDIMENTOLOGY

Previous Work

Based upon earlier work (McMillan, 1973; Pereira 'et al.', 1983), a number of observations were made with reference to the surficial sediments in the surveyed area which clearly demonstrate that the sedimentological history of the Hekja-Ralegh area is complex and a time-variable function of interactive processes. Factors which suggest this are:

1. Initial deposition of the surficial sediment blanketing this area of the shelf is believed to have taken place in a pro-glacial marine environment, possibly beneath or in front of a floating ice shelf (see MacLean, 1985). Huntec DTS profiles indicate an acoustically homogeneous sedimentary overburden, draping the older bedrock unconformity which is a relatively smooth surface (Figure 2). The sediment drape is about 7 m thick at the Hekja wellsite and pinches out at about 150 m water depth towards the coast line. In waters shallower than 150 m, patchy gravel and sand overlie the bedrock. In addition, lenses of glacial till have been reported in the Hekja-Ralegh area (Geonautics, 1982).
2. During the post-glacial time and through to the present the southeast Baffin Island shelf has been essentially a sediment-starved environment with only two potential sources of fresh sediment input. These are:

   a) Sediment input from the nearby Baffin Island fjords. Distribution patterns of these sediments and the amount of sediment input onto the shelf may possibly be determined by

examining the source area and the prevailing hydrodynamic regime.

b) Influx of sediment from ice and iceberg rafting (i.e. ice rafted detritus) is clearly evident but of an indeterminable quantity. Sediments from this extraneous source which are dumped onto the shelf distort the distribution patterns developed in 1 and 2a.

3. Vast amounts of surficial seabed sediments have been displaced by scouring iceberg keels. The subsequent redistribution of sediment by gravity and by the prevailing ocean currents is difficult to determine and this further distorts sediment distribution patterns developed above.

4. Areas of exposed bedrock are probably a consequence of iceberg scouring and/or ocean current scouring. In areas of relatively thin sediment overburden, sidescan sonar and Huntec DTS records clearly show that iceberg keels penetrate the sediment overburden through to the bedrock (Figure 2) and that subsequently no significant fresh sediment deposition or redeposition of this displaced sediment has taken place. This is interpreted to mean that the prevailing currents are of sufficient strength to inhibit sedimentation.

5. Sediment in the top 20 cm layer is relatively mobile as evidenced by sand ripples and current scour features. Hydrodynamic sorting of sediments is occurring actively as indicated in the core sample analysis.

6. Although none of the samples examined suggest that

bioturbation is an active phenomenon in the surveyed area, there is photographic evidence for the existence of epi- and infaunal organisms; some bioturbation of the upper layer must be taking place.

The above mentioned processes, acting in combination, lead to a complex sedimentological model for the areas studied. The results presented here reveal further insights into these processes.

Sediment Textural Analysis

The surficial sediment of the deeper southeast Baffin Island margin is currently believed to be concomitant to the glacio-marine Emerald Silt of the Scotian shelf and has recently been informally named the Davis Strait Silt (Praeg 'et al.', 1985). However, the Emerald Silt is finely laminated as indicated by Huntec DTS records, reflecting a relatively quiet depositional environment, possibly beneath an ice shelf (King, 1970). Repeated scouring of the Davis Strait Silt by icebergs has destroyed any lamination which may have existed except in a few localized, deeper water areas (Praeg, 'et al.', 'op. cit.'; see also Osterman, 1982).

In general, surficial sediment textures vary irregularly within the Hekja-Ralegh survey area. The textures range from areas of fine sand to areas with a wholly gravel cover; discrete trends correlative with observed environmental factors are not evident. The surficial sediments are generally clean, ranging in colour from olive green to greyish olive green and are loosely

compacted; the gravel content ranges between 0 and 100%. The gravel component is almost exclusively metamorphic rock fragments with lesser amounts of carbonate pebbles (e.g. limestone, dolostone, marble). Some of these pebbles and the occasional boulder seen in underwater photographs have a thick encrusting layer of calcareous algae indicating a prolonged time of residence on the seabed. Sediment in the silt to clay size comprise less than 5% of the samples (Table 3) whilst shell fragments and other biogenic material make up an even smaller fraction.

Sediment data from the Hekja-Ralegh area have been plotted on two ternary diagrams proposed by Folk (1980, p.26) in order to (a) classify the sediments and (b) determine whether any significant variations occur between samples. Figure 3a is concerned primarily with two factors: (1) the amount of gravel in the sample, and (2) the ratio of sand:mud. Within this classification, the Hekja-Ralegh samples plot as sandy gravels through to sands; a few of the samples are in the gravelly muddy sand field. According to Folk (1980), the gravel component of any sediment is highly significant since it is presumably a function of the highest current velocity at the time of deposition and the maximum grain size of available detritus. For the Hekja-Ralegh area this assumption is not strictly valid since all of the gravel here is derived either from a floating ice shelf or from icebergs; localized concentrations of gravel may occur on or immediately adjacent to iceberg scour berms due to winnowing (see Josenhans and Barrie, 1982).

TABLE 3

Textural Composition of Sediment Grab Samples from the Hekja-Ralegh Survey Site

Sample Number	Gravel	Sand	Mud
01	38	52	10
02	19	73	8
03	10	79	10
05	28	62	10
07	21	73	6
10	69	24	7
13	30	67	3
14	8	87	5
15	4	89	7
16	12	53	25
17	16	82	2
18	9	85	6
19	19	73	8
21	39	59	2
22	--	95	5
32	15	82	3
33	22	75	3
35	3	92	5
36	1	96	3
37	1	92	7
39	--	95	5
40	2	93	5
41	--	95	5

More applicable to the Hekja-Ralegh area is the sand:mud ratio which reflects the amount of winnowing at the site of deposition (Folk, 1980). Location of the Hekja-Ralegh samples almost exclusively in the sand field indicates that winnowing is an active process. This is supported by current meter data collected in the vicinity of the Ralegh wellsite which recorded maximum seabed bottom current velocities of up to 40 cm s^{-1} (Dobrocky Seatech Nfld. Ltd., 1982, Report for Canterra Energy).

If the gravel component is ignored (Figure 3b), nearly all of the samples plot as sand, with a few lying in the muddy sand field. The mud fraction in each comprises roughly 50:50 clay:silt. There is a slight increase in gravel and sand away from land whereas silt and clay do not show significant trends (Table 3).

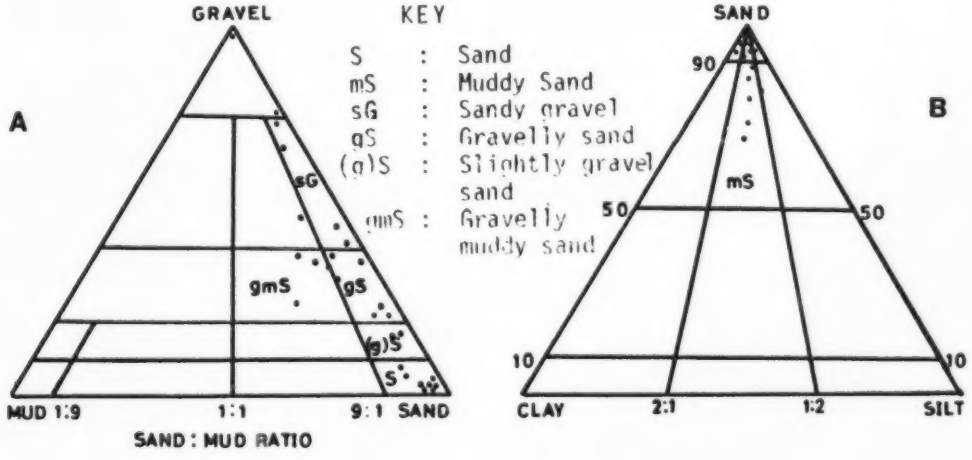


Figure 3. (a) Textural composition of surface sediment grab samples using the entire sample.

(b) Textural composition of surface sediment grab samples excluding the gravel component.

Grain Size Analysis

The statistical treatment of grain size distributions can be an effective discriminant in defining discrete depositional environments and, in some instances, it may be possible to isolate the individual factors that influence sediment distribution. However, it should be borne in mind that factors such as source rocks, grain size of available material, abrasion and the hydrodynamic regime influence the derived statistical values and subsequent interpretation. One of the more basic approaches to the understanding of the depositional history of a given sediment is through the analysis of the cumulative frequency distribution of the component grains. Cumulative curves have been found to be effective in hydraulic interpretations of grain size distribution (e.g. Visher, 1969) and give a quick measure of the deviation of a sample from a log normal distribution. Curves drawn for the Hekja-Ralegh samples reveal three obvious groupings based on curve shape (Figure 4).

The first group includes samples #03, 04, 06, 22, 36, 37, 39, 40 and 41 which are all characterized by an essentially normal (i.e. straight line) distribution in the gravel to fine sand range with a sharp break in slope at roughly 4 ϕ giving the curves a 'hockey-stick' shape.

The second grouping of curves include samples #01, 02, 05, 07, 17, 18, 19, 33 and 35 all of which are characterized by distinctive S-shaped curves comprised of coarse and fine tails. Breaks between the sections are generally rounded rather than sharp or angular.

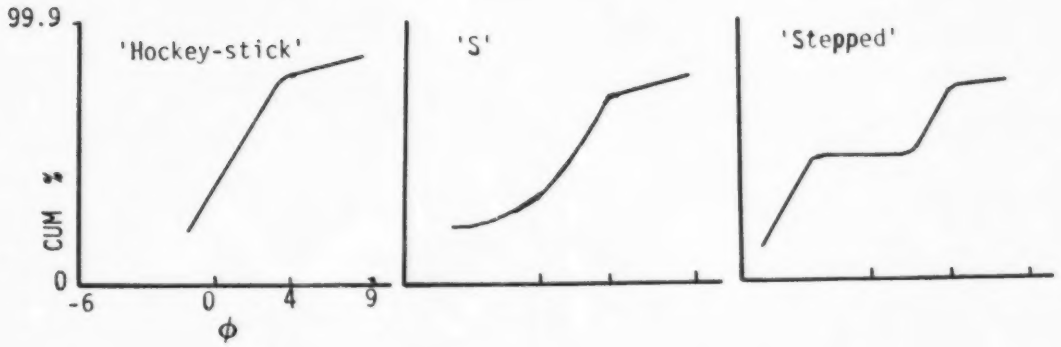


Figure 4. Generalized grain-size cumulative frequency curve shapes for Hekja-Ralegh samples.

The third grouping of curves include samples #10, 13, 14, 15 and 21 and are similar to the previously described S-shaped curves except that the breaks between curve segments are generally sharp and these curves also contain a fourth segment in the gravel range (-3 to -5 ϕ) with a relatively steep slope, lending a "stepped" character to the curves. The geographical distribution of these three cumulative curve groups is apparently random (Figure 5).

The interpretation and significance of curve shapes for the Hekja-Ralegh samples are problematic at this stage. The sediment source, environment and mechanics of initial deposition of these sediments are not precisely known. The broadly S-shaped form of many of the cumulative curves is similar to the shape yielded by fluvial sediments; however, as pointed out by Bridge (1981), it is doubtful whether any one curve type can represent one environment since transport and depositional mechanisms do not appear to be unique for different depositional environments.

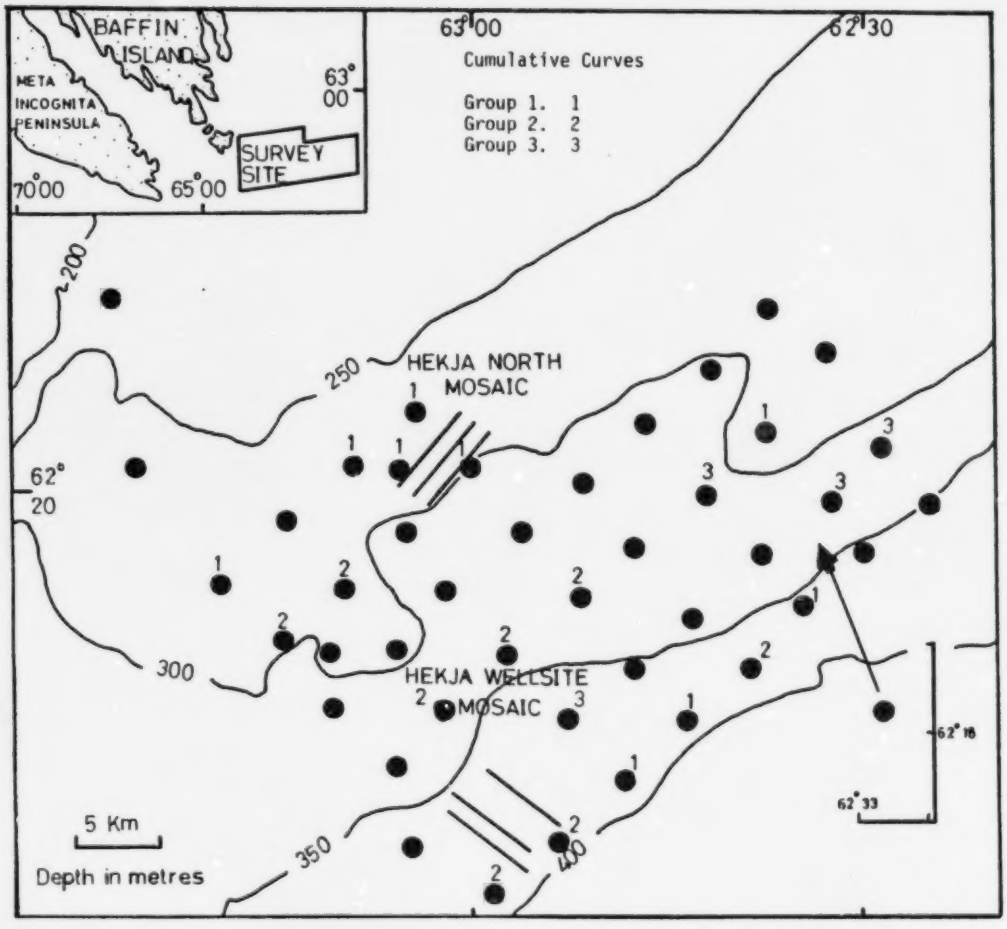


Figure 5. Map illustrating the random distribution of the three groups of grain size cumulative curves.

It is evident from sidescan sonar surveys that virtually all of the bottom sediment in the Hekja-Ralegh area has been thoroughly disturbed and redistributed by iceberg scouring (Barrie 'et al.', 1982; Pereira, 'et al.', 1983). For this reason, any initial deposition character has long since been modified. Detailed visual observations of iceberg scour morphologies by Josenhans and Barrie (1982) reveal generally gravelly berms with better sorted sediments in the scour troughs. These may be represented by the well sorted (hockey stick-shaped

cumulative curves) and more gravelly (S-shaped curves) samples found in the Hekja-Ralegh area. The samples with stepped cumulative distributions may represent areas outside individual scours, representing older scoured sediment mixed with relatively more recently ploughed up material.

As an additional step towards characterizing the surficial sediments, statistical parameters for the samples were calculated using the graphical methods of Folk (1980). These are:

1) Graphical mean size

$$M_z = \frac{\phi_{16} + \phi_{50} + \phi_{84}}{3}$$

2) Inclusive graphic standard deviation

$$\sigma_I = \frac{\phi_{84} - \phi_{16}}{4} + \frac{\phi_{95} - \phi_5}{6.6}$$

3) Inclusive graphic skewness

$$SK_I = \frac{\phi_{16} + \phi_{84} + 2\phi_{50}}{2(\phi_{84} - \phi_{16})} + \frac{\phi_5 + \phi_{95} - 2\phi_{50}}{2(\phi_{95} - \phi_5)}$$

4) Inclusive graphic kurtosis

$$K_G = \frac{\phi_{95} - \phi_5}{2.44(\phi_{75} - \phi_{25})}$$

The statistical data were derived from cumulative curves. The four statistical parameters are geometrically independant, but in some instances bivariate scatter plots of these parameters are helpful in delineating independant sub-populations. By use of these scatter plots it may be possible to segregate similar yet genetically distinct sediment sub-populations.

In spite of the highly irregular grain size distributions shown by most of the Hekja-Ralegh samples, four scatter plots which use these statistical parameters were drawn and are illustrated in Figures 6 and 7. For the Hekja-Ralegh samples, it was found that those samples which show an approximately normal distribution (i.e. unimodal, "hockey stick" shaped cumulative curve), plot as a distinct group while the remainder of the samples show significant scatter and no obvious groupings. The significance of the grouping of the sample stations with the "hockey stick" cumulative curves and the scattered distribution of the others with reference to what is known about the sedimentology and physical environment of the area is not clear; this perhaps emphasizes the complexity of the processes involved.

For purposes of comparison with the existing published data, raw data from the Hekja-Ralegh study area were recalculated to include only the granule to clay fraction; the various statistical parameters were determined from the reconstructed cumulative curves. Bivariate plots of the recalculated statistical parameters are given in Figures 8 and 9. The data compiled by Landim and Frakes (1968) for glacial till, glacial outwash and alluvial fan material are also included in these plots.

Figure 8a reveals that the Hekja-Ralegh sediments are generally better sorted than glacial till and have a slightly coarser mean grain size than both till and alluvial fan material. Figure 8b reveals that the Hekja-Ralegh sediments show roughly symmetrical to slightly coarse-skewed distribution. In Figure 9a

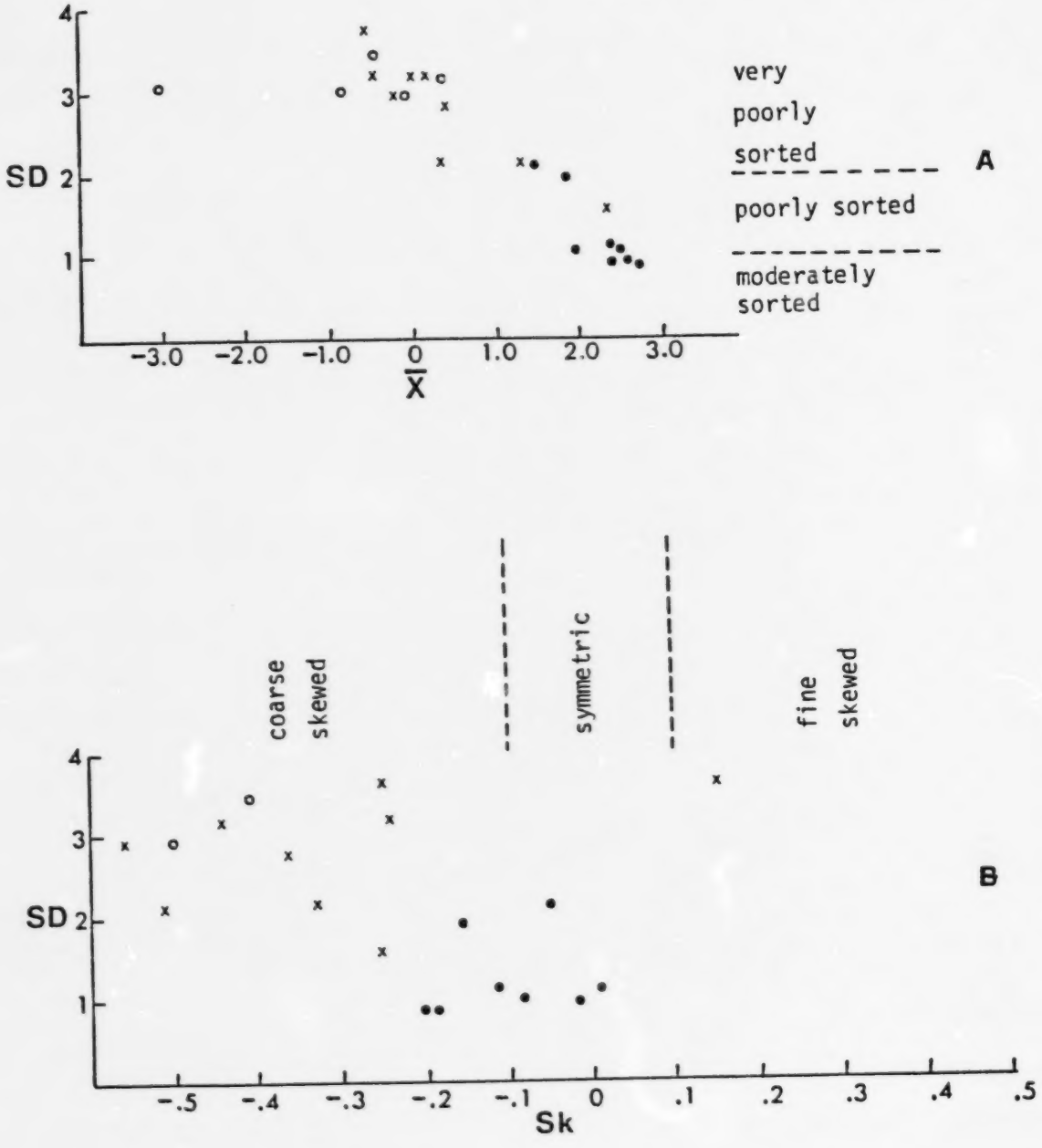


Figure 6 Bivariate plots of statistical parameters for surface grab samples from the Hekja-Ralegh area. Parameters have been derived from cumulative frequency curves

(a) Mean size versus standard deviation

(b) Skewness versus standard deviation

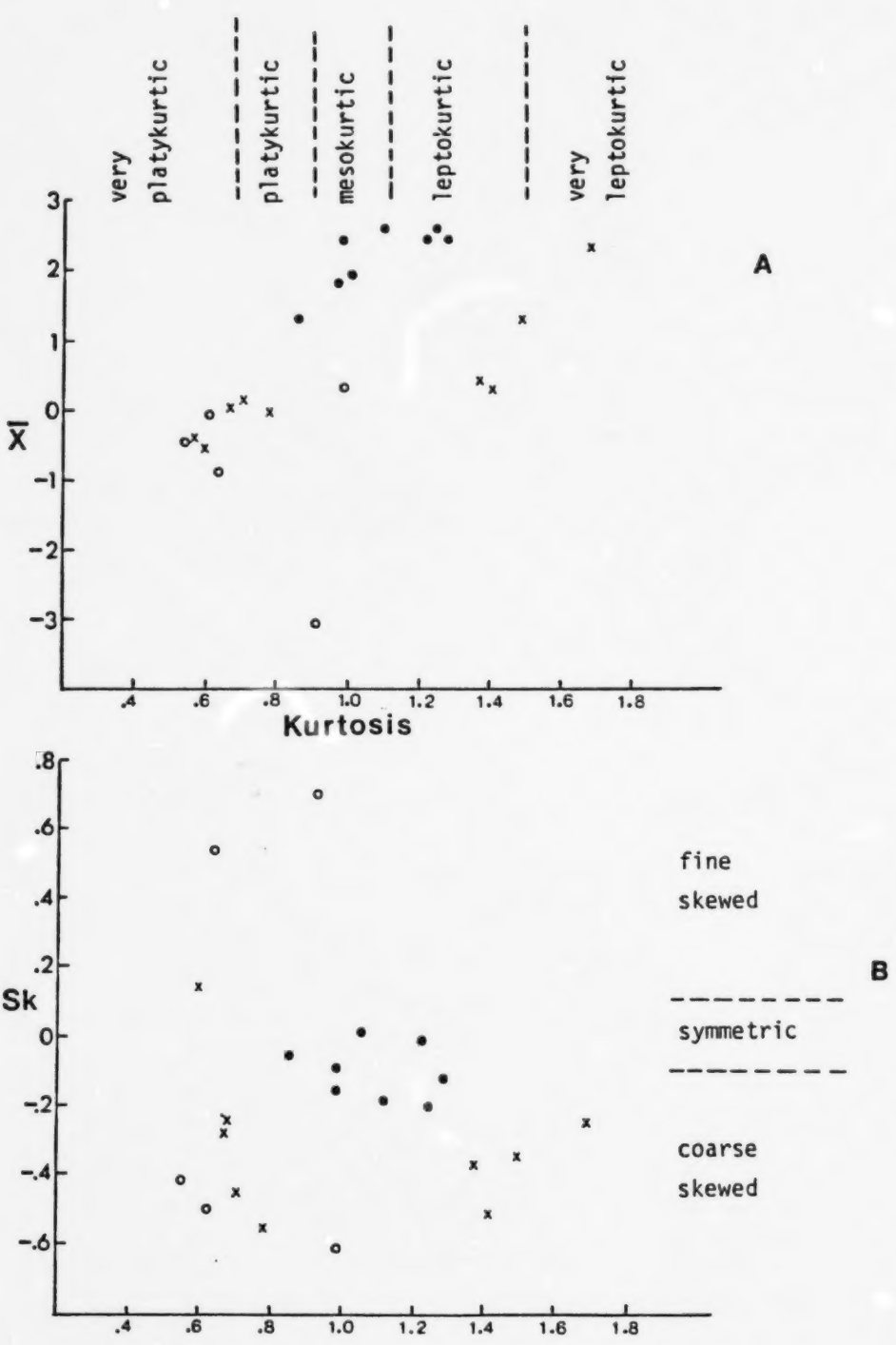


Figure 7 Bivariate plots of statistical parameters for surface grab samples from the Hekja-Ralegh area. Parameters have been derived from cumulative frequency curves

(a) Kurtosis versus mean size

(b) Kurtosis versus skewness

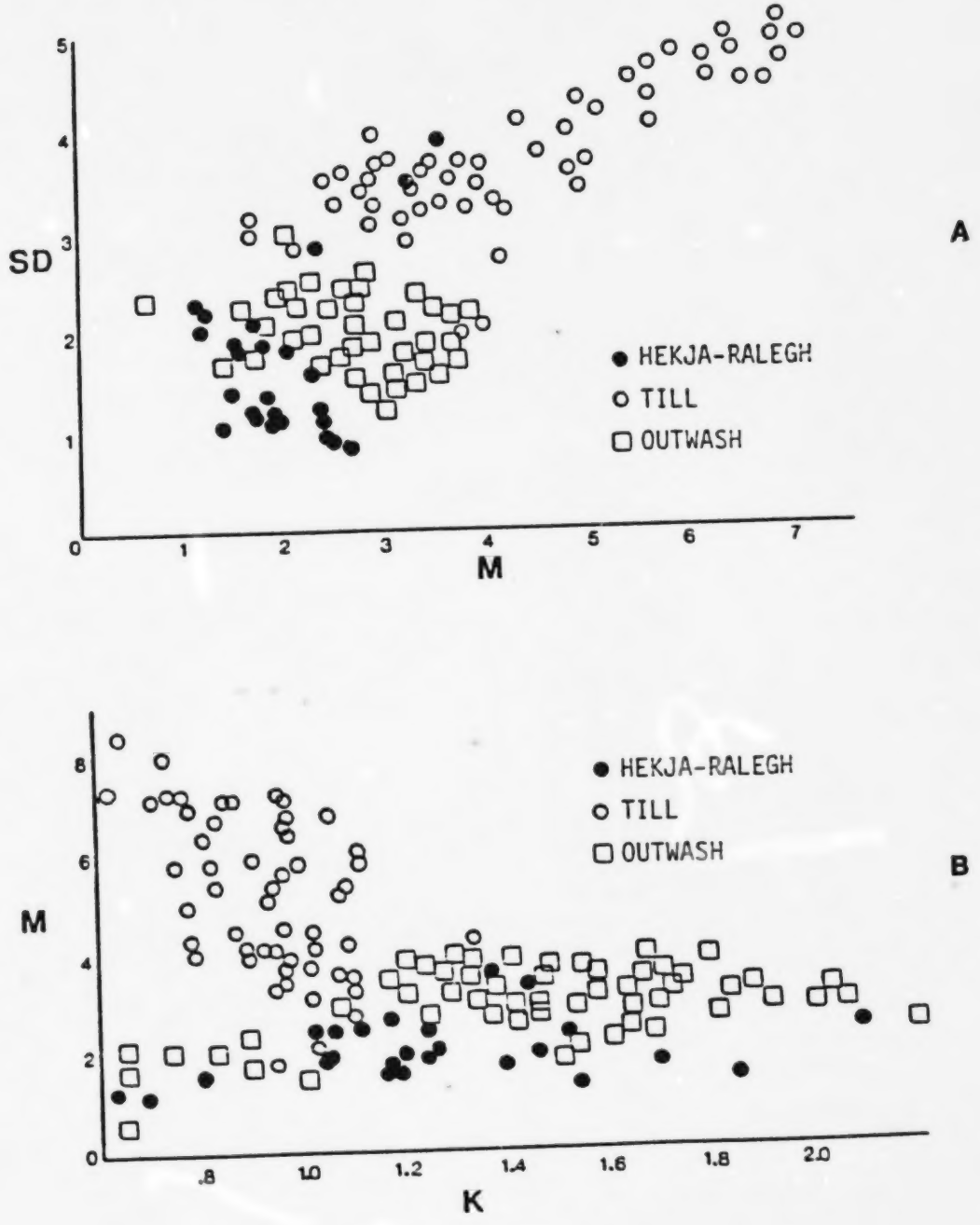
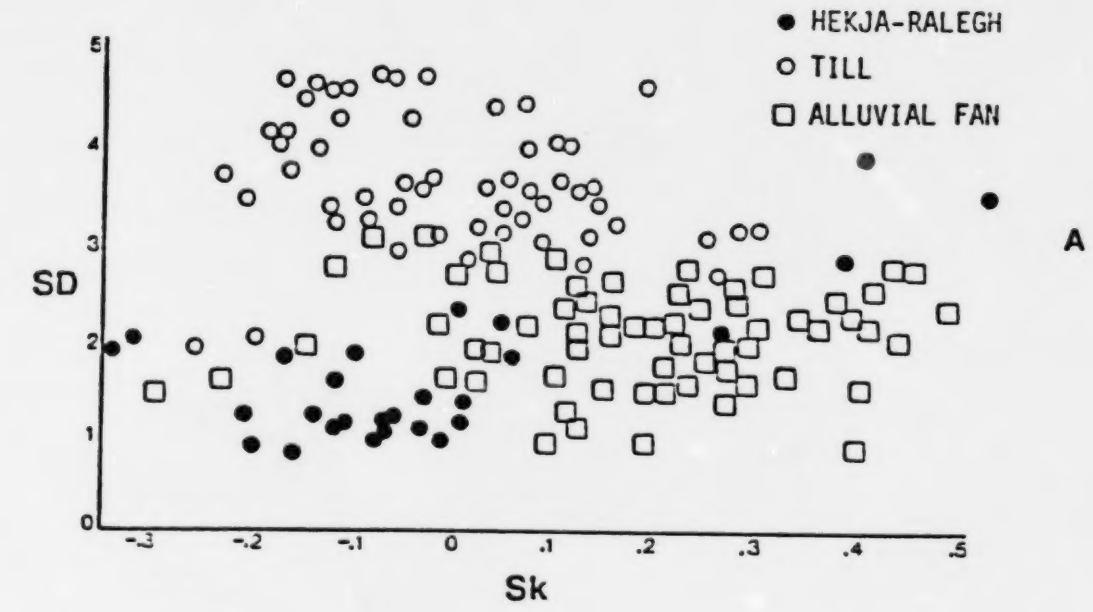


Figure 8 Comparison of Hekja-Ralegh sediments with data for till, alluvial fan and glacial outwash material (compiled from Landim and Frakes, 1968)

(a) Mean versus standard deviation

(b) Kurtosis versus mean size



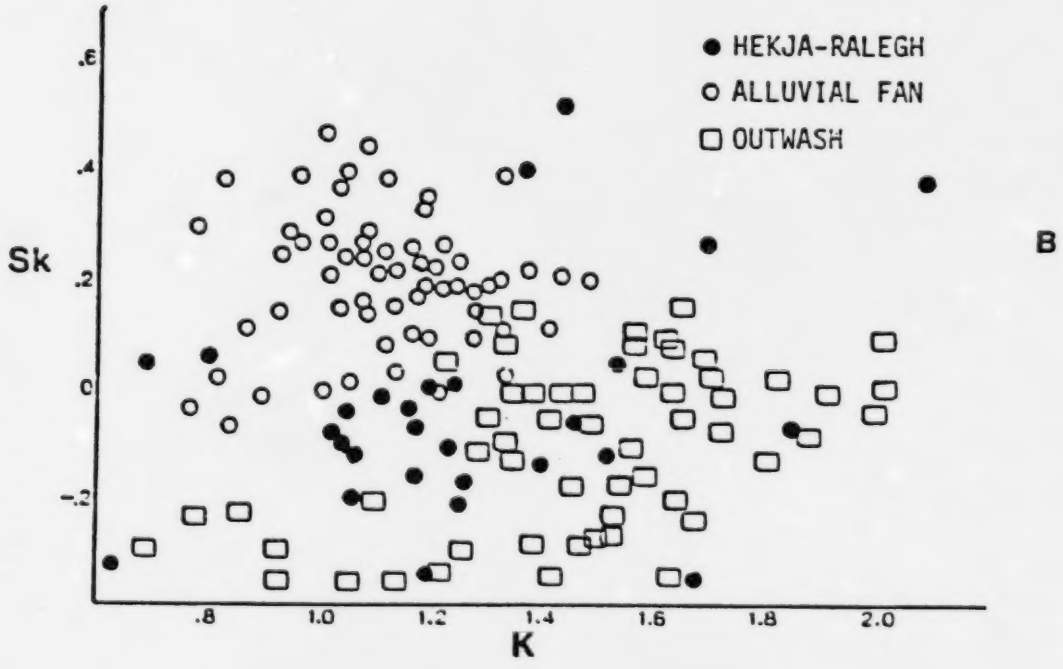


Figure 9 Comparison of Hekja-Ralegh sediments with data for till, alluvial fan and glacial outwash material (compiled from Landim and Frakes, 1968)

(a) Skewness versus standard deviation

(b) Kurtosis versus skewness

the Hekja-Ralegh samples show distribution which is roughly equivalent to that of glacial outwash except that they have a slightly coarser mean grain-size. The same broad correlation is also shown in Figure 9b.

It would appear then that sediments from the Hekja Ralegh area are generally better sorted than either glacial tills or alluvial fan material but closely resemble glacial outwash material. In general they show a coarser mean grain size than all three. Sorting by bottom currents subsequent to the initial deposition of the sediments in a glaciomarine environment is suggested as a primary mechanism.

CORE LOGGING

Seventeen cores from the Hekja-Ralegh survey area were split and described. Their general characteristics are described briefly in this section. Detailed core descriptions and the accompanying statistical grain size analysis of sediment subsamples are given in Pereira and Gillespie (1983).

Eight of the cores contained a light yellowish-green, clean, quartz sand surface layer between 0.5 and 6 cm thick. The occurrence of this layer was not restricted to any one area of the survey but appeared to be random. The surface layer of the remaining cores were either well compacted clays or large pebbles. Whether these different surface layer types can be related to scouring (i.e. points on either a scour berm or scour trough) or to current reworking is difficult to assess. To answer these questions, it would be necessary to undertake a more thorough investigation of the hydrodynamic regime.

The presence of dark grey/blackish bands was common to nearly all the cores. These were never evenly distributed throughout the cores and occasionally degenerated into indistinct black mottles. Separate grain size analyses showed that there were no grain size differences or gradations between the bands. The sediment between these dark grey bands was characteristically coloured olive grey to light grey. Occasionally the dark grey/black bands gave off a weak H_2S odour. Breaks in sediment texture (attributed to a scouring event) were clearly evident in some of the cores; and in such instances, subsampling around this section of the core was exhaustive.

All the cores contained gravel sized sediment distributed randomly throughout but only four of the cores had pebbles in them. In two of the cores, the pebbles were lodged about half way down the core. Sediment on either side of the pebbles was undisturbed indicating that the pebbles had been embedded in the sediment during deposition or mixing by iceberg scouring, rather than having been pushed in by the core barrel.

STRATIGRAPHIC CORE ANALYSIS

Sediments

Of the 52 cores retrieved, 17 were examined sedimentologically and of these 15 were analysed for their micropalaeontological content and stratigraphical history. These were core nos. 07, 09, 12, 20, 22, 25, 27, 31, 37, 38, 40, 41, 43 and 44 (2 cores) (Figure 1). Core lengths varied between 10.5 and 120 cm. Cores collected from within the Hekja North mosaic area (Core No. 41) and from the mud volcano (Core No. 43) were also examined (Figure 1).

The cores were routinely subsampled at 10 cm intervals and at horizons that indicated a marked change in either sediment colour or a rapid change in sediment texture; the two sometimes coincided. In general, the gravel and sand content decreases with depth while the silt and clay fractions show a corresponding increase. The most marked and rapid textural changes from sand to silt and clay occur in the top 10-20 cm. This coarser top 10-20 cm reflects 'in situ' hydrodynamic sorting. Most of the samples have a broad log-Gaussian grain size distribution with modes which range from 2 to 4 ϕ and a definite modal shift from coarse to fine, down the core is noted in some cases (Pereira and Gillespíe, 1983). A few of the samples within any given core have a weak to fairly strong second mode in the -2 to -1 ϕ size range which probably reflects input from ice rafted material.

Of the cores examined, the majority exhibit a homogeneous sediment distribution from top to bottom with no sharp textural breaks evident, except for a narrow band of better sorted

material at the top of most cores. A number of the cores, however, demonstrate marked textural changes at specific points along their lengths. Examples of a normal and broken succession are discussed in detail below.

Normal Succession

Core number 22 (120 cm length) is typical of those cores which show a normal, undisturbed sediment succession (Pereira and Gillespie, 1983). Cumulative curves constructed for each of the subsamples indicate broadly normal frequency distributions (i.e. approximate a straight line) and frequency distribution curves indicate a constant modal distribution with depth. Notably, the distributions do become less peaked with depth down the core (a trend which is not reflected by calculated kurtosis values which remain relatively constant). Sorting, as indicated by standard deviation, also remains constant with depth. Since the top 20 cm of this core were not analysed, the abrupt textural changes which characterize the top of virtually all cores examined are not evident. These changes invariably involve a definite modal shift from coarse at the surface to fine just below the surface. The sediment at the surface is also generally better sorted.

Other cores which exhibit a normal textural succession are Nos. 09, 12, 25, 31, 37, 40, 41 and 44 (2 cores).

Broken Succession

Four of the cores examined, Nos. 07, 20, 27 and 38, exhibited marked sediment textural changes at single points along their length. Core number 07 is described below as an example.

The top 60 cm of core number 07 are characterized by sediments which show a normal log-Gaussian grain size distribution (Pereira and Gillespie, 1983). As with all cores examined, the surface sub-sample shows much better sorting and a coarser mean grain size value than sub-samples from just below the surface.

At a depth of 64 cm the sub-sample demonstrates a markedly anomalous distribution which is strongly positively skewed (excess coarse material) and contains no less than four weak modal groupings. Below this level the grain-size distribution returns to a more normal pattern with a single mode at 3.5 ϕ .

Microfossils

A normal succession of microfossil deposition is exhibited from most of the cores that were examined. Of the 15 cores examined only 5 have a marked and distinctive break in their microfossil succession; these breaks occurred in core Nos. 07, 20, 25, 27 and 38 (Figure 1). All except core No. 25, also demonstrated concurrent changes in their sedimentology. A brief description of the microfossil succession follows commencing with a description of core No. 22, which records a continuous microfossil succession with no apparent disruption or break. This is the control core (Figure 10) to which three of the five

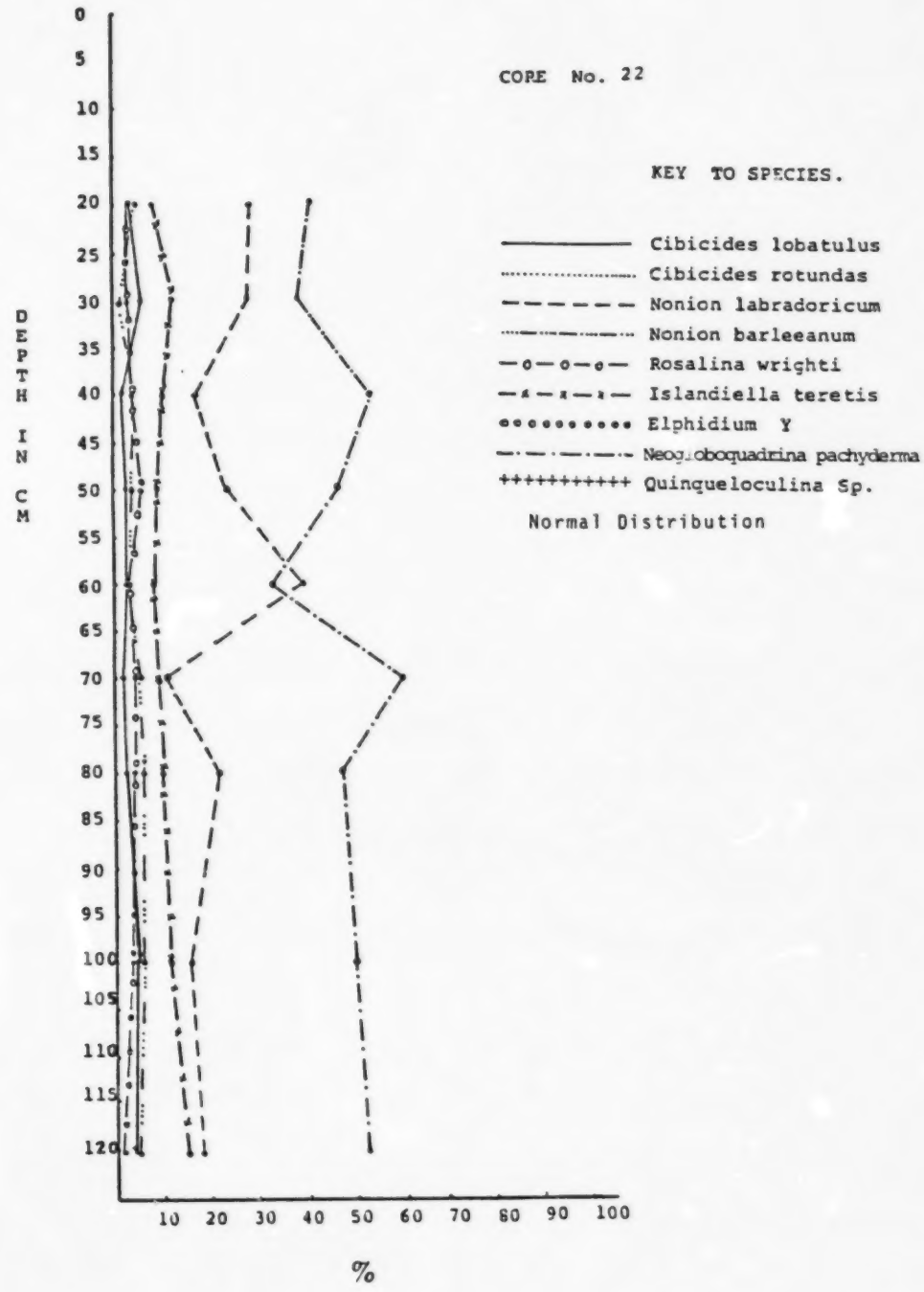


Figure 10 Graphical representation of foraminiferal frequency along the length of the control core (Core No. 22) collected north of the Ralegh Wellsite

cores mentioned above are compared. Microfossil succession of the cores not described in this text are illustrated in Pereira and Gillespie (1983).

The top 20 cm of core No. 22 is clean, medium to fine sand with very little mud and associated microfauna. At about 20 cm depth, there is a marked and distinctive change from sand to silty clay which dominates the core thereafter. Figure 10 shows the distribution curves of the dominant species within the sample core and, as is clearly evident from the graph, all the species have a normal succession except at the 60 cm interval. It should be noted that although the bottom 40 cm were sampled at 20 cm intervals, the underlying normal trend of microfossil succession is clearly evident. In contrast to this, the five cores mentioned above, three of which are described below, have markedly different stratigraphical histories.

In core No. 7 (Figure 11) microfossil succession is randomly mixed from the bottom of the core upward to the 50 cm interval; two species make a pronounced and dominant occurrence between the 50 and 60 cm interval. At the 50 cm interval, species **Elphidium Y** has a sudden and pronounced appearance (along with **Cibicides rotundas** at the 60 cm interval), and has a 50% occurrence. Neither of these species, which are relatively large (about 2 mm or more in diameter), and have thick, robust skeletons (which are extensively abraded) are found in the top section of the core. From the 50 cm interval to the top of the core the microfossil distribution is normal and similar to that described in core No. 22 (Figure 10). The topmost 10 cm records a mixed distribution

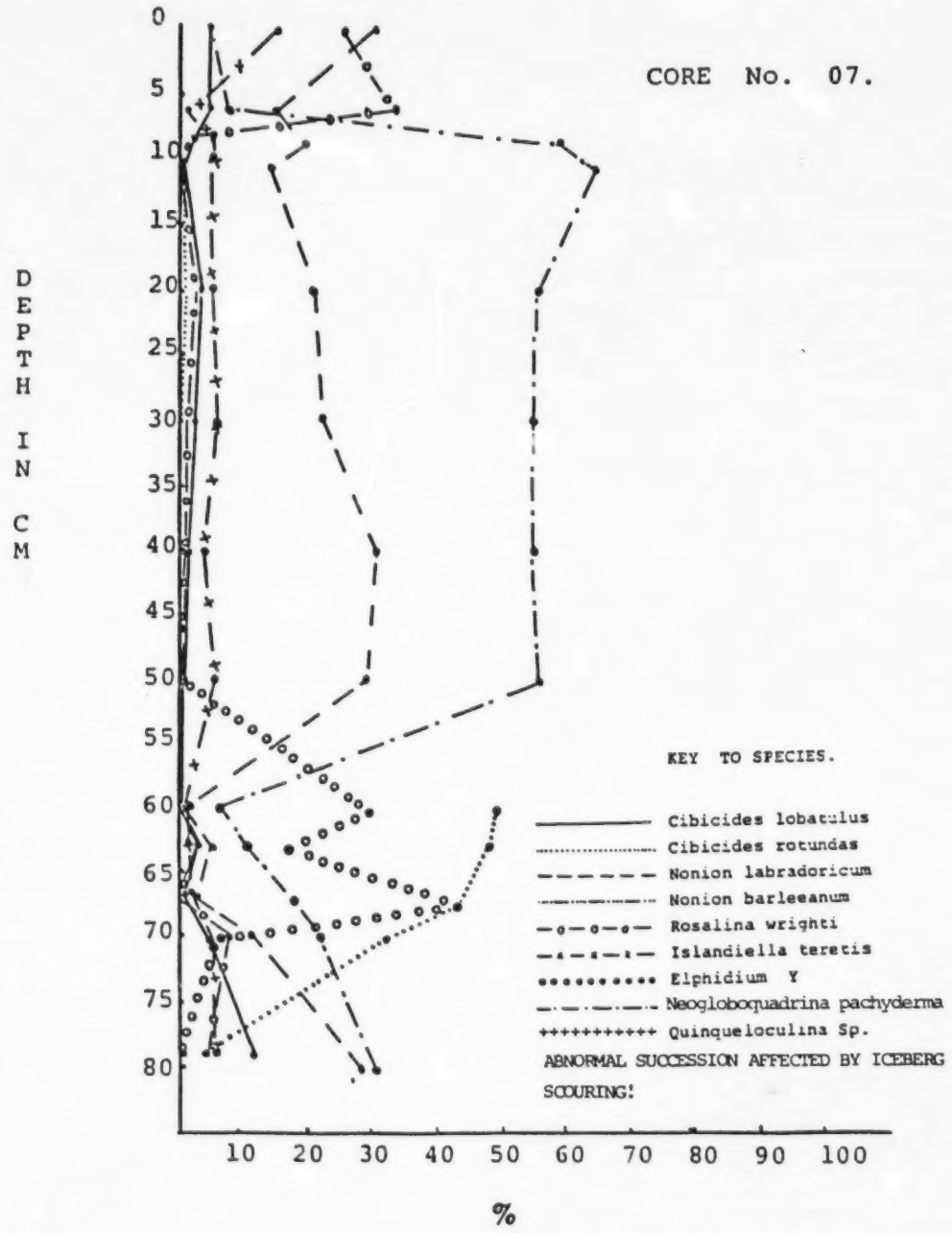


Figure 11 Graphical representation of foraminiferal frequency, Core No. 07, collected immediately east of the Ralegh Wellsite. Scouring event inferred at the 65 to 70 cm level

of microfossils (characteristic of most surface samples that were examined).

Core No. 20 (Figure 12) has a normal distribution of species between 5 and 17 cm and between 45 cm and the core bottom section with the intervening section displaying an anomalous distribution pattern. A change in the sediment texture occurs at the 40 cm interval. In contrast to core No. 7, new species do not appear at the break; instead there is a sudden, increased occurrence of one of the indigenous dominant species (**Nonion labradoricum**) to the microfossil successional occurrence.

In core No. 27 (Figure 13), the distribution curve for the various species is not clearly defined, nevertheless the underlying trends are obvious. From the bottom of the core to about the 50 cm interval, the distribution of the various species is apparently normal; at that point the distribution shows a marked change. In this sample there appears to be a 10 cm lag behind the sedimentological change, but by about the 30 cm interval, the distribution curves tend toward the normal until the top few centimetres of the core. Unlike core No. 7, additional species do not make an appearance, but there does appear to be a rearrangement of the frequency of occurrence of the indigenous population probably due to the selected winnowing away of the smaller, lighter specimens.

The three cores described above clearly indicate that at the breaks indicated by the sedimentological and microfossil succession, some form of a relatively sudden catastrophic event must have taken place. It is suggested that all these

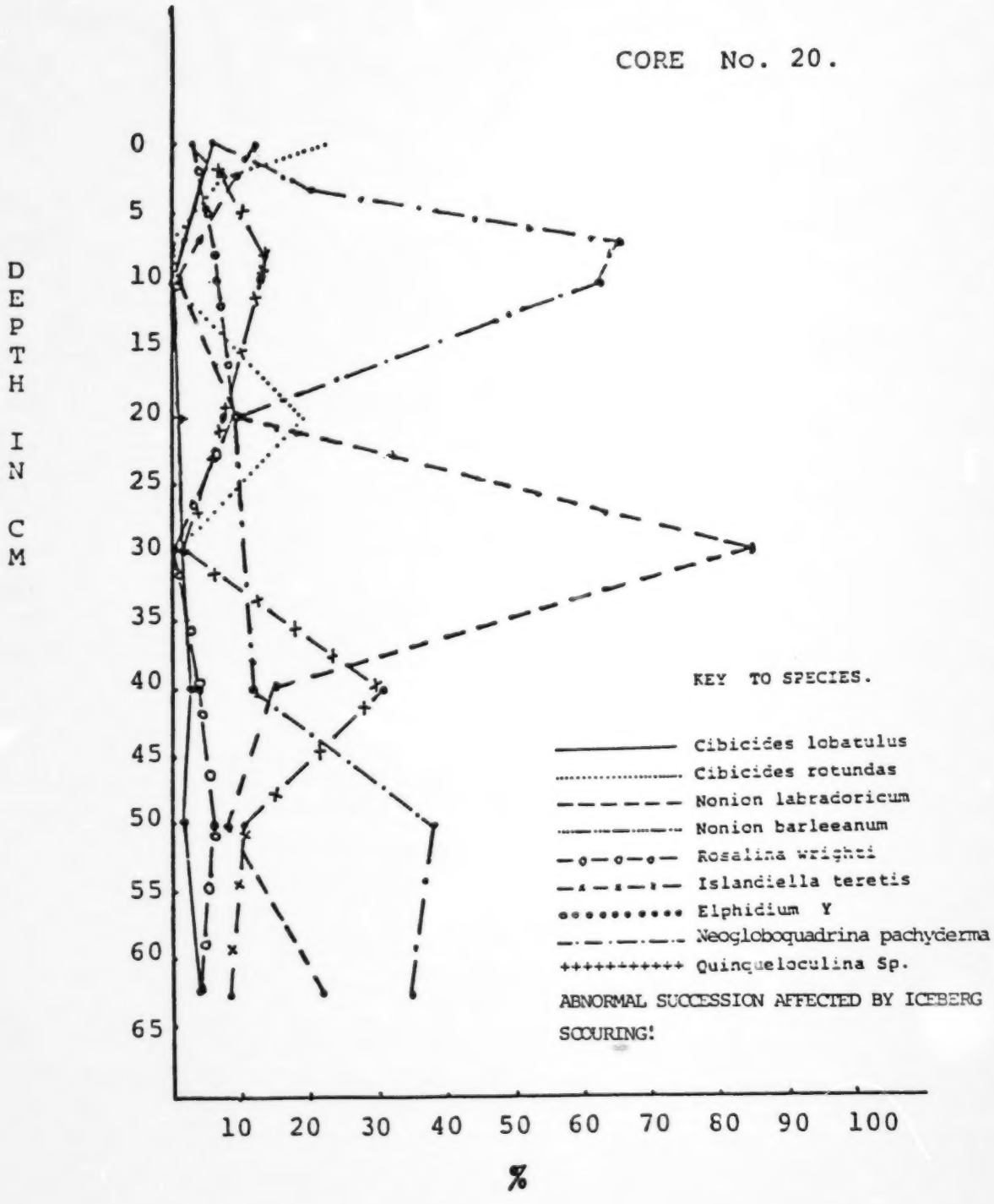


Figure 12 Graphical respresentation of foraminiferal frequency, Core No. 20, collected west of the Ralegh Wellsite

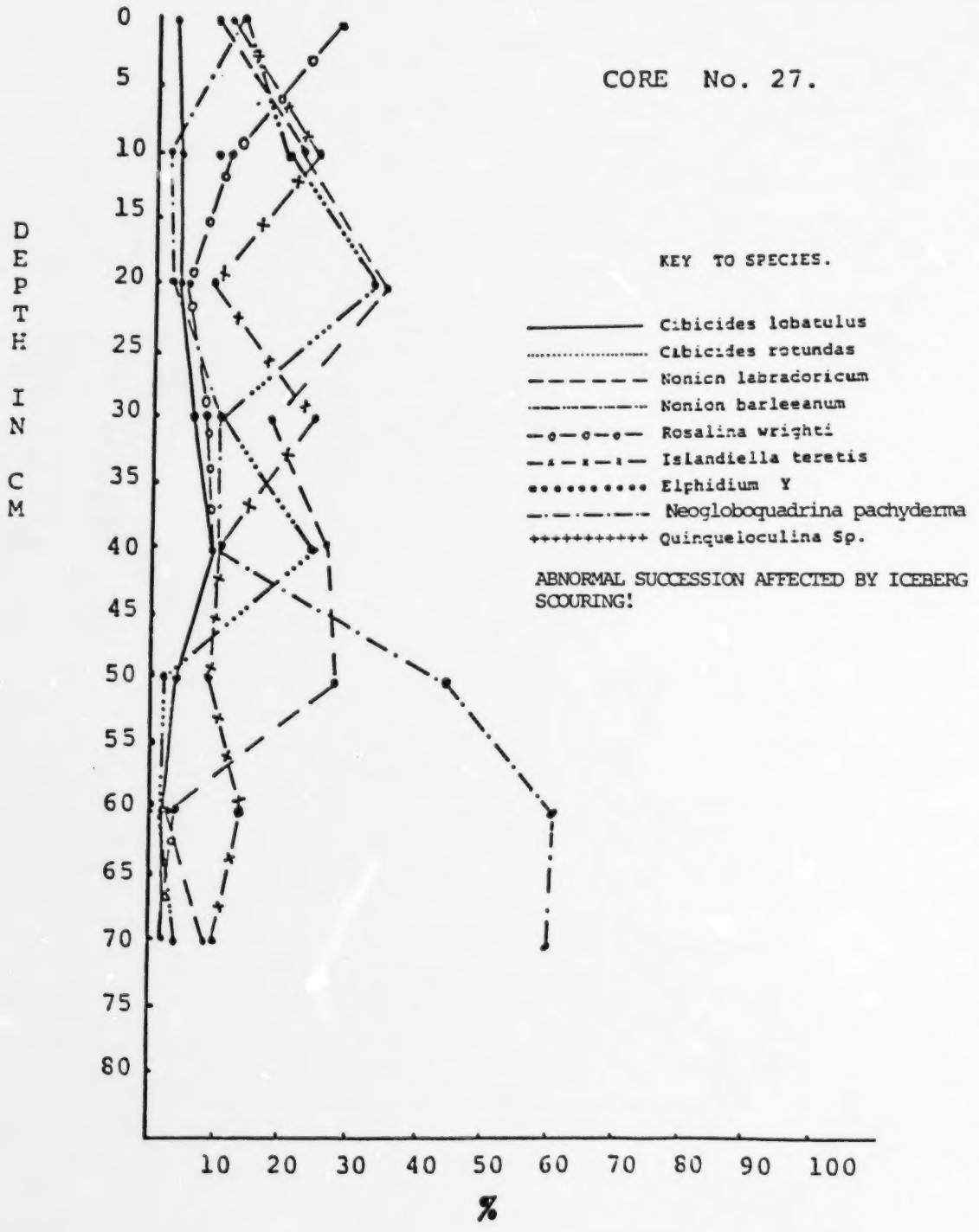


Figure 13 Graphical representation of foraminiferal frequency, Core No. 27, collected north of the Hekja Wellsite

occurrences are either directly or indirectly related to iceberg scouring and may reflect different points of core collection relating to iceberg scour features i.e., the cores may have been collected from the berm, a little distance from it or from various points within the scour trough.

The remaining two areas of interest from which cores were collected were the Hekja North mosaic area and the site of the mud volcano. Core No. 41 collected from the Hekja North mosaic area revealed a normal distribution (similar to that of Figure 10) with no significant breaks in the microfaunal succession (Pereira and Gillespie, 1983).

Core No. 43 is taken from a broad, conical seabed feature interpreted as a submarine mud volcano (Woodworth-Lynas, 1983). In terms of sediment character this core is unlike any of the others examined in that it is extremely bimodal with strong modes at -2 and 3.5 ϕ . This distribution pattern does not change with depth; however, considering the short length of the core (15.5 cm) this pattern is inconclusive. Frequency distribution and cumulative frequency curves for this core are given in Pereira and Gillespie (1983).

The microfaunal succession of core No. 43 is not dissimilar to that of a normal occurrence. In the first 6 cm, distribution is apparently chaotic (similar to that found in the other cores) but toward the bottom, distribution tends toward the norm. It should be noted that the core is very short and hence the results should be considered inconclusive. Nevertheless, it does seem anomalous to have collected such a small core from a structure

interpreted to be a mud volcano (and by implication, covered by a relatively thick cover of sediment). The short core, sediment analysis and microfaunal evidence do not conclusively prove or disprove the existence of the mud volcano. Further investigations of this problem are required, since its existence may be a significant hazard to exploration, especially if it is of recent origin.

TABLE 4

Location of Cores Used in the Geotechnical Analyses

Core Number	Latutude	Longitude
1	62°06.41'N	62°56.74'W
11	62°13.51'N	62°45.55'W
17	62°12.36'N	63°00.38'W
23	62°23.25'N	62°30.32'W
24	62°12.47'N	63°00.56'W
26	62°16.26'N	62°59.21'W
29	62°21.59'N	62°44.22'W
44	62°18.06'N	62°32.50'W
44	62°10.04'N	62°32.48'W
44	62°18.01'N	62°32.51'W

GEOTECHNICAL ANALYSIS

Geotechnical tests were conducted on 10 core samples (Table 4) by Chari 'et al.' (in Pereira and Gillespie, 1983) and included in the final contract report to Canterra Energy Ltd. (Pereira and Gillespie, 'op. cit.'). The tests on the cores were undertaken according to standard ASTM procedures; summary results of some of the tests and conclusions are included in this text.

Natural Moisture Content

The natural moisture content gives the relative proportion of water and sediment in a given soil mass on the seabed and is thus an indirect indicator of the voids in the sample. The natural moisture content of the samples tested is in the average range of 20%, and the extreme values varied from a low of 17.5% to a high of 42%.

Bulk Density

The bulk density of a sample depends upon several associated factors including soil type, degree of sample disturbance and sample size. Nevertheless bulk density values may tentatively be taken as an indicator of the 'in situ' sea floor density. The bulk density for the samples tested were in the range of 2050 to 2100 kg/m^3. This corresponds to densities normally obtained for loose to compact sand.

Atterberg Limits

The plastic limit and liquid limit were determined for all ten samples and shrinkage limit was determined for some representative sub-sections of each core. The results indicate that the plasticity index is relatively small except in those portions of the core with high clay content. In the surficial sub-samples the natural water content is close to the liquid limit which is to be expected.

Summary

Geotechnical tests of the core samples from the Hekja and Ralegh sites indicate that the surface layers are inorganic silts and silty clays with medium to low plasticity. The surface is compact and appears to be somewhat resistant to penetration by the gravity corer. This is evident from the length of core samples retrieved and the bulk density, which is in the order of 2000 kg/m^3. However, it is desirable to investigate the layering of the sediments and examine if there are any weak seams. This will be necessary if the problem of slope stability is to be analysed in any significant detail. The natural water content is close to the liquid limit. The average angle of shear resistence may be taken as 25^o for these samples.

SUMMARY DISCUSSION AND MODEL

Geophysical surveys and bottom sampling indicate a homogenous, poorly sorted sandy silt unit draping the outer continental shelf bedrock, which is itself overlain by a surficial (0-20 cm) layer of gravelly sand. The sandy-silt unit (equivalent to Davis Strait Silt of Praeg 'et al.', 1985) records the intense scouring by icebergs. The temporal occurrence of iceberg scouring is not known and it is a critical question that needs to be answered.

Three major factors affecting the mechanics and frequency of ice scour are the mass and shape of the icebergs and water depth; these factors may vary over the period of scouring. Water depth, in particular, is critical in the interpretation of the past and present scouring environments since changes in sea level will greatly affect the frequency of scouring. The sea level record is closely related to climatic change and consequently glacier advance and retreat; this in turn affects iceberg production at calving margins. To date, studies on the sea level fluctuations for this area have concentrated on the coastal cliff exposure of the southern and lower eastern portion of Baffin Island (Andrews, 1980; Miller 'et al.', 1980). The results of these studies suggest that in certain surveyed areas on the southeast of the Baffin Island coast, relative sea level has fallen between 20 to 120 m since 11,000 BP but that at present the eastern Baffin Island coast and Loks Land are being submerged either in response to increased water load on the continental shelf caused by the late Pleistocene sea level rise, or the migration of a forbulge

through the area (Miller 'et al.', 'op. cit.'). Unfortunately, it is not possible at present to extrapolate these results to the area of interest in this study, but the results do indicate that relative sea levels for the marine area may have fluctuated greatly during the Holocene period (see also Aksu, 1977). Correlation of the cores examined in this study with Hekja 1981 core suggest that the scouring events recorded in the cores range between 5,000 and 15,000 years in age and thus some may predate the Hall ice advance of 10,760 B.P. Using this as a guideline, and assuming that iceberg drafts have remained fairly constant over time, it is reasonable to suggest that sea level was relatively lower at the time of scouring in the area. Existing iceberg draught data for the Labrador Shelf indicate few icebergs with draughts in excess of 230 m (Hotzel and Miller, 1983). Additional information on the regional distribution and mode of deposition of Quaternary sediment would be necessary before an effective glacial/sea level model could be developed.

The maximum amount of material found above any interpreted scour break is 50 cm, suggesting sediment accumulation rates of between 0.1 and 0.3 mm/year over the elapsed 5,000 to 15,000 years since scouring. This assumes that sediment accumulates at a constant rate within the scour troughs. Recent work on relict scours now exposed on land in the central Arctic indicates that where scour infill does occur it may occur almost immediately following passage of the iceberg keel (C. Woodworth-Lynas, C-CORE, pers. comm., 1985). This is in contrast with some of the Huntec DTS records for the Baffin Island shelf which suggest that

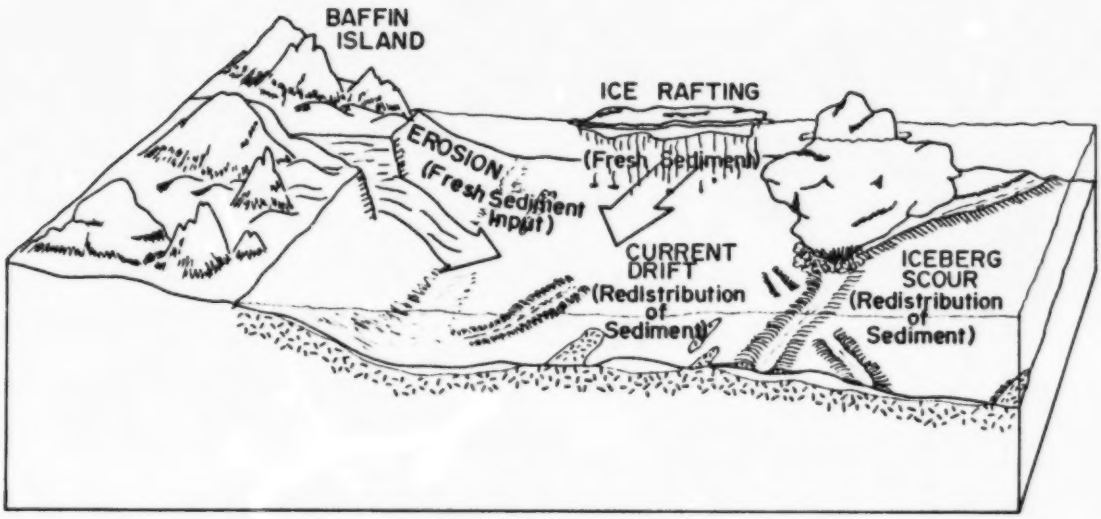


Figure 14 Generalized model of physical processes influencing and contributing to sedimentology of the southeast Baffin Island continental shelf

little if any sediment infill has occurred subsequent to scouring.

Illustrated in Figure 14 is a sketch which synthesizes the major physical processes influencing and contributing to the sedimentology of the southeast Baffin Island continental shelf in the Hekja-Ralegh area. Initial sedimentation is interpreted to have taken place in a glaciomarine environment, possibly beneath a floating ice shelf (MacLean, 1985). Standard treatment of sieve and pipette data for surface samples from the sedimentary unit reveal a number of influences in terms of sediment source and physical processes. Comparison of textural data with published

data for glacial till, outwash and alluvial fan material (Landim and Frakes, 1968), reveals a similarity to glacial outwash. Iceberg scouring has since disturbed and redistributed the bottom sediments. Bottom currents have removed most of the surficial silt and clay within the top 10-20 cm of the sediment which accounts for the paucity (<5%) of such material. Iceberg rafting is probably responsible for a fraction of the total sediment including the anomalous coarse gravel fraction found in many samples.

CONCLUSIONS

The present marine environment on the continental shelf southeast of Baffin Island is not dominated by any one sedimentary process. Most of the surficial sediment presently found on the shelf was deposited beneath a floating ice sheet probably during the Foxe glaciation or earlier. Modern sediment input onto the shelf occurs primarily from two sources: (1) erosion of the adjacent land mass contributes sediment to the inner shelf which is then moved farther offshore by the strong ocean currents recorded for this area and (2) ice rafting of sediment onto the outer shelf, by ice and icebergs. Overall, sedimentation rates are probably very low in this area. The surficial seabed in this area may be likened to a ploughed "farmer's field". Iceberg scouring combined with ocean current activity, has thoroughly disturbed, reworked, and homogenized the initial surficial sediment deposited. Bottom currents have sorted the top layer of sediment effectively. Bottom photographs in the Hekja area clearly show that some large expanses of gravel pavement exist at these depths, and further support the theory that extensive current winnowing is a dynamically active process (Pereira 'et al.', 1983). The variable distribution of sediments evident within the study area clearly indicates that a much more thorough and exhaustive study is necessary before a proper assessment of the practicality of major seabed installation may be made. This view is also supported by the preliminary geotechnical study.

Relative sea level changes for the surveyed area were not determinable since the cores retrieved were of insufficient length to reveal any environmental changes reflected in the fauna or in sediments. Nevertheless, comparison of results with land based studies suggests that the icebergs that scoured the bottom need not necessarily have been of the dimensions suggested by the depths at which the scours are recorded presently.

The stratigraphic analysis of the cores clearly indicates that sudden, marked changes in sedimentological and microfossil content do occur, and that these most probably reflect scouring events by icebergs. Longer cores that penetrate through to the bedrock could give a much better picture of how often scouring reoccurs over the same area. Absolute ages for the scouring events recorded in the cores were not obtainable, primarily due to the fact that it was not possible to obtain sufficient quantities of biogenic carbonate for radio-isotopic dating from the cores. Nevertheless comparison with amino acid racemization results from a core collected at the Hekja wellsite in 1981 indicates that the scouring events recorded in the cores probably predate the Hall glaciation of 10,760 years ago.

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